THE ESA PROSPECT PAYLOAD: SCIENCE ACTIVITIES AND DEVELOPMENT STATUS.

D. Heather[1], E. Sefton-Nash[1], R. Fisackerly[1], R. Trautner[1], S. J. Barber[2], B. Houdou[1], S. Boazman, the PROSPECT Science Team* and Industrial Consortium. [1]ESTEC, European Space Agency, Keplerlaan 1, Noordwijk 2201AZ, Netherlands (David.Heather@esa.int), [2]The Open University, Walton Hall, Milton Keynes, UK.

*Feargus Abernethy, Mahesh Anand, Simeon Barber, Sebastien Besse, Neil Bowles, John Brucato, Abigail Calzada-Diaz, James Carpenter, Luke Chipperfield, Barbara Cohen, Aidan Cowley, Ian Crawford, Gabriele Cremonese, Maria Cristina De Sanctis, Simone Di Angelis, Kerri Donaldson-Hanna, Carlos Espejel, Marco Ferrari, Richard Fisackerly, Michelangelo Formisano, Teresa Fornaro, Evelyn Fueri, Mikhail Gerasimov, Fred Goesmann, Laura Grill, Christian Gscheidle, Christophe Hissler, Hung Q. Hoang, Katherine Joy, Akos Kereszturi, Julian Klaus, Julian-Alexandre Lamamy, Michèle Lavagna, Mark Leese, Maxim Litvak, Veneranda Lopez-Diaz, Paolo Lunghi, Dayl Martin, Francesca McDonald, Jeffrey McDonnell, Andrea Meneghin, Giada Meogrossi, Igor Mitrofanov, Andrew Morse, James Mortimer, Csilla Orgel, Laurent Pfister, Jacopo Prinetto, Andrea Rusconi, Guido Sangiovanni, Hannah Sargeant, Nicole Schmitz, James Schwanethal, Christian Schwartz, Simon Sheridan, Romain Tartèse, Vlad Tretyakov, Sasha Verchovsky, Ulrich Walter, Tristram Warren, Kris Zacny

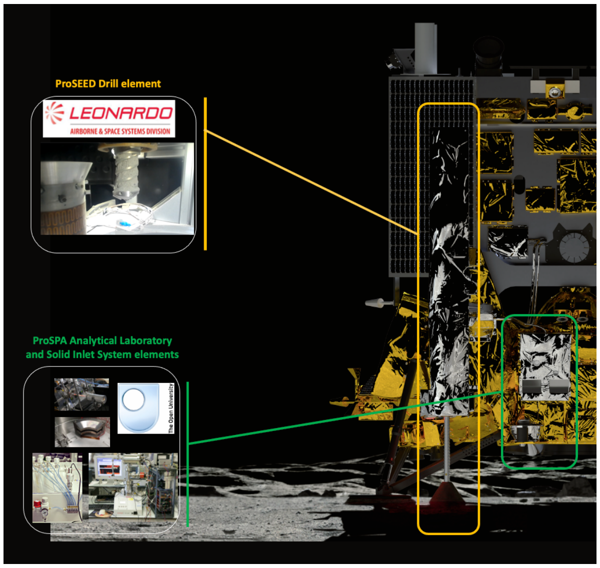
Introduction: The Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) is a payload in development by ESA for use at the lunar surface. Original development was for implementation on the Russia-led Luna 27 mission, but this has now shifted to potential flight on a NASA CLPS lander to the lunar south polar region in late 2026.

Additional flight opportunities for PROSPECT related hardware are also in development / ready for flight. These include two implementations of the ion trap Exospheric Mass Spectrometer (EMS) element, one on the Astrobotic Peregrine-1 mission (scheduled for flight early this year) [1], and a second on JAXA's LUPEX rover, for flight in the 2025 timeframe.

PROSPECT Overview: PROSPECT will perform an assessment of the volatile inventory in the near surface lunar regolith (down to ~ 1 m), and complete elemental and isotopic analyses to determine the abundance and origin of any volatiles discovered [2]. PROSPECT also has ISRU capabilities and will aim to complete in-situ extraction of oxygen (and solar wind implanted volatiles) from lunar minerals, which will constitute potential science return from anywhere on the Moon, regardless of volatile content. PROSPECT is comprised of the ProSEED drill module and the ProSPA analytical laboratory plus the Solids Inlet System (SIS), a carousel of sealable ovens for evolving volatiles from regolith (Figure 1).

The ProSEED drill is capable of collecting two icy samples of different sizes and mechanical properties in a single sampling operation, one of up to 45 mm^3 and a second up to 8 cm^3, with the smaller sample delivered to ProSPA for analyses. The second, larger sample would potentially be available to other payloads. The drill rod also has integrated temperature sensors and a sensor to measure the electrical permittivity of the lunar soil along the borehole.

The ProSPA laboratory will receive samples from the drill, seal them in miniaturized ovens, and process them via ramped (EGA), stepped (isotopic) or single step (ISRU) heating up to 1000 °C, completing physical and chemical processing of released volatiles, and analysing the obtained constituents via Ion Trap or Magnetic Sector mass spectroscopy.



Credit: ESA, Leonardo and Open University

Figure 1: *Rendering of PROSPECT on a polar lander, including the ProSEED drill module, and ProSPA. ProSPA comprises 1) the Solids Inlet System (SIS), and 2) the Analytical Laboratory (AL).*

ProSEED and ProSPA will also each carry small cameras. The ProSEED Imaging System (IS) has multispectral capabilities via 6 LEDs, which can illuminate the surface with wavelengths ranging from 451 to 970nm. This will provide images and video of the drill working area to monitor activities and deliver contextual scientific information. ProSPA's Sample Camera (SamCam [3]) has its own specific illumination unit with similar capabilities to the ProSEED IS and will image the samples before they are sealed in the ovens, providing information on their morphology, grain size, volume and mineralogy.

Development status: PROSPECT is currently at the Critical Design Review (CDR) stage, with most unit level CDRs and the ProSEED CDR completed last year. The CDR for the SIS and the ProSPA AL are ongoing, and the system wide CDR for PROSPECT is expected later this year.

In parallel to the industrial schedule and reviews, an associated plan of research activities has been formulated to gain from and guide ongoing development, build strategic scientific knowledge, and to prepare for operation of the payload. This included testing of the ProSEED IS Engineering Model by the Science Team in 2021, measuring the spectral profile of each of the LEDs, and characterizing the geometric, radiometric and spectral response of the camera, and assessing the impact that dust deposition may have on the camera sensitivity. Some further activities are described below.

The ProSPA Bench Development Model (BDM). at the Open University has been tested to demonstrate science performance against measurement requirements. This included verification of evolved gas analysis (EGA) via measurement of meteorite standards, constraint of oxygen yield via demonstration of ISRU capabilities [4, 5], and a better understanding of the performance of oven seal materials [6].

Volatile Preservation: PROSPECT's scientific success is strongly dependent upon its ability to sufficiently preserve the regolith's volatile content throughout the sampling-analysis chain for the range of expected volatile contents, e.g. [7]. Detailed modelling and experimental work is ongoing to better understand water sublimation rates in realistic lunar surface operational environments, regolith structures, and geometries [8], and to better constrain the potential effect on measured D/H of sublimation of lunar water ice (for example, elaborating from [9]). Results from this work will help ensure that even in a 'hot operational case', the original volatile inventory can be determined with sufficiently small uncertainties.

Science Activities: a few examples of science activities being pursued alongside and in support of the technical development are noted below.

Cleanliness and contamination: A key activity in the last year has been an assessment of the approach being used for managing cleanliness and contamination throughout the instrument development and implementation, ensuring that contamination will remain at permissible levels and that science objectives can be met. Work on the ProSPA BDM fed into this study, with an improved understanding of sensitivity of science requirements to regolith volatile abundance and possible contaminants. As a result, a Contamination Framework has been developed (Figure 2) to account for all key vectors that will contribute to contamination, with simulated performance of the ProSPA Analytical Laboratory to allow for science level assessments to be made. This is currently being studied within the science team, and the objective will be to develop the existing Framework into a contamination budget within the coming months.

Science Mode	Species	Isotopes or Mass Measured	Analysis Method	Mass spectrometer detection limit (mg per measurement duration (for EGA, Isotopes, and ISRU) or mbar (for Background Exosphere))	Is sample scenario above detection limit?	Signal to Noise Ratio	Is Measurement Possible? (Green = YES, Black = NO)
Background Exosphere	H_2O	18	Dynamic, steady state pressure	9,02E-10	✗	0,068	⬛
	Ar	40	Dynamic, steady state pressure	5,36E-10	✗	386889,46	⬛
	CO_2	44	Dynamic, steady state pressure	5,36E-10	✗	0,000038	⬛
Sample Composition/ Concentration (EGA)	CO_2	44	Dynamic (gas in 10 second pulse)	0,00000041	✓	1,12	🟩
	H_2O	18	Dynamic (gas in 10 second pulse)	0,000000031	✓	3,22	🟩
	H_2	2	Dynamic (gas in 10 second pulse)	n/a	n/a	0,81	🟩
	N_2	28	Dynamic (gas in 10 second pulse)	0,0000018	✓	0,7414	🟩
	O_2	32	Dynamic (gas in 10 second pulse)	0,00000043	✗	3,33E+00	⬛
	[C] organics	16	Dynamic (gas in 10 second pulse)	0,00000011	✓	2,58	🟩
Sample Isotopic Composition	CO_2	13C/12C	Pyrolysis, Static	0,0000044	✓	9,18	🟩
	CO_2	13C/12C	Pyrolysis, Dynamic (gas in 10 second pulse)	0,022	✗	0,95	⬛
	CO_2	18O/16O	Pyrolysis, Static	0,0000044	✓	9,18	🟩
	CO_2	18O/16O	Pyrolysis, Dynamic (gas in 10 second pulse)	0,022	✗	0,95	⬛
	H_2O	D/H	Pyr, PtC, Dynamic (gas in 10 second pulse)	0,002	✓	1,80	🟩
	H_2O	18O/16O	Pyr, Pt C, Static	0,0000016	✓	17,88	🟩
	H_2	D/H	Pyrolysis, Dynamic (gas in 10 second pulse)	0,002	✓	1,30	🟩
	N_2	15N/14N	Pyr, static	0,0000028	✓	1,02	🟩
	O_2	18O/16O	Pyrolysis, Dynamic (gas in 10 second pulse)	0,016	✗	0,00004	⬛
	O_2	18O/16O	pyr, Pt C, Static	0,000016	✗	0,00038	⬛
	[C] organics	13C/12C	combustion, static	0,0000044	✓	17,33	🟩
ISRU	H_2O	18	Dynamic (gas in 10 second pulse)	0,000000031	✓	0,29	⬛

Key (Backgr. Exosp.)	Good Detection (S/N ≥ 3)	🟩
	Fair Detection (S/N ≥ 1, < 3)	🟨
	Poor Detection (S/N < 1)	🟥
Key (Sample Composition/Concentration (EGA))	Good Detection (S/N ≥ 3)	🟩
	Fair Detection (S/N ≥ 1, < 3)	🟨
	Poor Detection (S/N < 1)	🟥
Key (Sample Isotopic Composition)	Good Isotopic Measurements (S/N ≥ 10)	🟩
	Fair Isotopic Measurements (S/N ≥ 3, < 10)	🟨
	Poor Isotopic Measurements (S/N < 3)	🟧
	Isotopic Measurements Not Possible (S/N < 1)	🟥
Key (ISRU)	Good Detection (S/N ≥ 3)	🟩
	Fair Detection (S/N ≥ 1, < 3)	🟨
	Poor Detection (S/N < 1)	🟥

Credit: Mortimer et al.

Figure 2: *Simulated performance of ProSPA using Contamination Framework.*

Operations planning: Currently, NASA CLPS missions do not offer lunar night-time survival capabilities, although there are options being investigated to change this in future. The lack of guaranteed night-time survival means a much-reduced operational lifetime for PROSPECT than was previously envisaged. The compressed schedule will mean little or no time for scientific analyses between operational sequences, and there is considerable effort currently being put into developing a robust plan to allow for more automated science level commanding and operations that will maximise the science return.

CAPTEM sample analysis: In 2020, PROSPECT Science Team members successfully requested two samples of lunar regolith (2 g each) from the Apollo collections (14163 and 69921). The proposed experiments will investigate loss of water ice through sublimation and the effects that the bulk properties and the ice-regolith coupling have on the sublimation process.

Landing site analyses: PROSPECT's success is strongly driven by the landing site, and considerable effort is being placed into surveying the south polar region to select some suitable candidates for PROSPECT. These will be fed into the landing site selection process for the given NASA CLPS mission after PROSPECT is officially manifested [10].

References: [1] Cohen, B. A. et al., (2019) in *Annu. Mtg. Lunar Explor. Anal. Group.*[2] Trautner, R. et al., (2018) in *Proc. Int. Astronaut. Congr. IAC*, Vol. 2018-October. [3] Murray, N. J. et al. (2020) in *Lunar Planet. Sci. Conf.,* LPI, Abs #. 1918. [4] Sargeant, H. M. et al., (2020) *Planet. Space Sci. 180* (104751). [5] Sargeant, H. M. et al., (2020) in *Lunar Planet. Sci. Conf.* LPI, Abs #. 2058. [6] Abernethy, F. A. J. et al., (2020) *Planet. Space Sci. 180* (104784). [7] King, O. et al., (2019) *Planet. Space Sci.* 104790. [8] Formisano, M. et al., (2019) *Planet. Space Sci. 169*. [9] Mortimer, J. et al., (2018) *Planet. Space Sci. 158*, 25–33. [10] Boazman, S. et. al., (2023) in *Lunar Planet. Sci. Conf.* LPI, *this meeting.*